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Influence of spacing on the initial production of hedgerow 'Arbequina' olive orchards

L. León[1]*, R. de la Rosa[1], L. Rallo[2], N. Guerrero[3] and D. Barranco[2]

[1] *IFAPA. Centro Alameda del Obispo. Avda. Menéndez Pidal, s/n. 14004 Córdoba. Spain*
[2] *Departamento de Agronomía. Universidad de Córdoba. Campus de Rabanales. Edificio Celestino Mutis. Ctra. Madrid-Cádiz, km 396. 14014 Córdoba. Spain*
[3] *Todolivo, S. L. Ingeniero Torroja y Miret, s/n. 14013 Córdoba. Spain*

Abstract

A new type of olive (*Olea europaea* L.) orchard, based on high-density hedgerows harvested by vineyard type straddle-harvesters has appeared in recent years. This system greatly simplifies olive harvesting, which has a high labour demand in standard olive orchards. There are, however, no specific low-vigour olive cultivars or dwarfing rootstocks adapted to this system, as exist in other fruit crops. It is therefore crucial to select the optimum density for maximum production without causing serious competition problems. In this study we present initial results of the effect of densities, ranging from 780 to 2,580 olive trees ha^{-1}, on the production of an 'Arbequina' olive hedgerow orchard during the first seven years after planting. There were no significant differences in fruit characteristics (oil content and moisture) among density treatments. Density had a linear negative influence on fruit yield tree^{-1}. In contrast, accumulated yield ha^{-1}, for both fruit and oil yield, showed a linear increase with increased density, with coefficients of determination ranging from 0.37 to 0.72. Accumulated oil yield at high density was up to 5,000 kg ha^{-1} more than at the low density.

Additional key words: high density, mechanical harvesting, *Olea europaea* L., planting density.

Resumen

Influencia de la densidad en una plantación en seto de olivo de 'Arbequina'

En los últimos años ha aparecido un nuevo tipo de plantaciones de olivo (*Olea europaea* L.), basada en setos de alta densidad de plantación, que son recogidos por máquinas cabalgadoras similares a las de los viñedos. Este sistema simplifica de forma significativa la recolección del olivar, que es una labor que requiere gran cantidad de mano de obra en las plantaciones habituales. Sin embargo, no hay cultivares de poco vigor o patrones enanizantes que estén adaptados a este sistema, como sucede en otros frutales. Así, es crucial seleccionar la mejor densidad para tener una óptima productividad sin serios problemas de competencia entre árboles. En el presente estudio se muestran los resultados iniciales del efecto de la densidad, que varía de 780 a 2.580 árboles ha^{-1}, en la productividad de una plantación en seto de la variedad 'Arbequina', durante los primeros siete años de vida. No se han encontrado diferencias significativas para los caracteres de fruto (contenido en aceite y humedad) entre las distintas densidades. Ésta tuvo una influencia linear y negativa en la cosecha por árbol. Por el contrario, la cosecha acumulada por hectárea, tanto en aceituna como en aceite, mostró un aumento linear con la densidad, con coeficientes de determinación que variaron entre 0,37 y 0,72. El aceite acumulado en las densidades más altas fue superior en más de 5.000 kg ha^{-1} respecto a las densidades más bajas.

Palabras clave adicionales: alta densidad, densidad de plantación, *Olea europaea* L., recolección mecánica.

Introduction

In the last few years a new type of olive orchard, suited to fully mechanized harvesting, has appeared. Trees are planted in rows at a very high density, of around 2,000 trees ha^{-1}, compared to 200-400 trees ha^{-1} in standard olive orchards. Due to the small distance between trees, a hedge is formed 2-3 yr after planting. Vineyard type straddle-harvesters are used to collect the fruit. The main advantage of these types of orchards is the lower cost of harvesting compared to standard olive groves, due to the marked reduction in the labour needed to harvest the crop.

* Corresponding author: lorenzo.leon.ext@juntadeandalucia.es
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L. León, R. de la Rosa, L. Rallo and D. Barranco are members of the SECH.

Although there are no reports on the area cultivated with hedgerow olives, the practise is increasing rapidly in various countries such as Spain (Navarro and Parra, 2004; Tous *et al.,* 2007), Italy (Godini *et al.,* 2006), Morocco, Tunisia and the United States (Berenguer *et al.,* 2006). However, very few experiments have been reported on the best conditions and viability for this type of olive orchard (Pastor *et al.,* 2005; De la Rosa *et al.,* 2007; Tous *et al.,* 2007).

Many fruit crops such as cherry, pear and apple have been planted at high densities as low vigour plant material has been developed. This is especially true for apple, which has been studied the most (Brooks and Olmo, 1997; Dennis and Hull, 2003). Different olive cultivars exhibit different vigour levels, but a true dwarf cultivar or dwarfing rootstock does not exist. The primary cultivars used in high density systems tend to be very precocious, such as 'Arbequina', 'Arbosana' or 'Koroneiki' (De la Rosa *et al*., 2007; Tous *et al.,* 2007), but they can not be considered to be low vigour cultivars. Tree vigour could be a problem in very favourable growing conditions, such as that in Andalusia, southern Spain, since hedgerows must be kept below certain dimensions to allow harvesters to pass over the top of the row.

Given the lack of specific low vigour cultivars choice of an optimum density could be a critical factor in the success of high-density olive orchards. High density trees should have their highest yield in the first years of growth but are likely to suffer from mutual shading problems later on. Vigour will be more difficult to control by pruning as reported in apple (Hampson *et al.,* 2004). Recent studies on olive hedgerow orchards have shown the importance of planting design (orientation, row height, row width and canopy slope) to identify combinations that maximize incident solar radiation interception and, thus, productivity (Connor, 2006). However, there is little information on the influence of olive tree density on yield, and the few reported studies were conducted in standard olive orchards (Pastor and Humanes, 1990; Tous *et al.,* 2005).

This work reports on the influence of olive tree spacing on production during the first seven years from planting of a high-density hedgerow olive orchard grown in the South of Spain (Andalusia).

Material and Methods

The trial was located in Pedro Abad, Cordoba, Spain (longitude 4° 27' 37'' W, latitude 37° 57' 43'' N and altitude 155 m) with an average rain fall of 477 mm year^{-1}. Average mean, maximum and minimum temperatures are 17.2, 24.5 and 10.2°C respectively (Gavilán *et al.,* 2006). Ten densities treatments, ranging from 780 to 2,581 trees ha^{-1}, were evaluated in four individual blocks. Different densities treatments were obtained by varying the distance between rows from 5.7 to 3.1 m and between trees in the row from 2.25 to 1.25 m (Table 1). Each plot (per treatment and block) consisted of a 40 m long row, with 18 to 32 trees depending on density. The cultivar 'Arbequina' was planted in March 2000 in a north-south hedgerow orientation. Irrigation applied was 1,800-2,300 m^3 ha^{-1} yr^{-1}. Trees were trained to a monocone shape (central leader), eliminating vigorous lateral branches to allow unimpeded access of the harvesting machine every year. Phytosanitary treatments against *Spilocaea oleagina* and *Margaronia unionalis* were applied with a maximum of 6 yr^{-1}.

From 2002 to 2006 yield and fruit characteristics (oil content and moisture) were measured. This was three to seven years after planting. In 2003, unusually heavy rain prevented harvest of the trial and data collection (4th year after planting). The fruit were subsequently removed to avoid interference with following year's production. The olives were harvested with a vineyard-type harvester model «Gregoire 120» (2.60 m high and 0.8 m wide) and were measured for each row of each treatment and block. Three 30 g random samples of olives were collected from the crop from each row to determine fruit characteristics. Samples were dried in a forced-air oven at 105°C for 42 h. Dried samples were weighed to determine moisture content and then oil percentage was measured in an NMR analyzer Minispec NMS100 (Bruker Optik GmbH, Ettlingen, Germany) following Del Río and Romero (1999).

Table 1. Olive tree densities used in the experiment

Tree density (trees ha^{-1})	Between rows (m)	Between trees (m)
780	5.70	2.25
909	5.50	2.00
952	5.25	2.00
1,143	5.00	1.75
1,203	4.75	1.75
1,481	4.50	1.50
1,569	4.25	1.50
2,000	4.00	1.25
2,254	3.55	1.25
2,581	3.10	1.25

Table 2. Response of fruit characteristics to tree density of the 3rd, 5th, 6th and 7th year after planting. Differences among density treatments within years were not significant ($P > 0.05$)

Density (trees ha^{-1})	Oil content on a fresh weight basis (%)				Moisture (%)			
	3rd	5th	6th	7th	3rd	5th	6th	7th
780	15.4	17.6	21.1	23.3	62.1	57.2	53.1	51.7
909	16.2	18.7	21.8	23.5	57.6	55.3	52.7	51.4
952	17.0	20.5	21.4	22.4	59.3	55.3	53.2	52.6
1,143	16.8	19.4	22.7	22.9	59.0	56.2	51.9	51.6
1,203	16.1	21.6	20.9	21.0	60.0	56.1	53.5	54.1
1,481	17.1	19.5	21.1	23.1	59.6	57.4	53.8	51.5
1,569	16.4	17.7	21.0	23.0	59.7	56.3	53.4	51.2
2,000	15.2	20.7	21.3	23.0	61.5	56.9	53.9	52.6
2,254	15.1	17.3	21.8	23.9	60.9	56.4	52.9	51.2
2,581	14.7	17.2	21.6	23.0	58.7	57.0	53.4	52.3
Average[A]	16.2d	19.0c	21.5b	23.0a	59.8a	56.4b	53.0c	51.9d

[A] Letters indicate significant differences between years for each characteristic (Tukey, $P < 0.05$).

ANOVA and regression analyses were performed to determine the influence of density on production characteristics using Statistix (Analytical Software, Tallahassee, FL, USA).

Results

There were no significant differences in fruit characteristics among densities in any year of the study (Table 2). However, differences among years were highly significant ($P < 0.05$).

In all cases there were significant linear regressions between density and yield. Increased density negatively influenced yield tree^{-1}, with coefficients of determination ranging from 0.37 to 0.56 in the years under study (Table 3, Fig. 1). In contrast, yield ha^{-1} increased linearly with increased density with coefficients of determination ranging from 0.42 to 0.72 for fruit yield (Table 3, Fig. 2) and from 0.41 to 0.69 for oil yield (Table 3, Fig. 3).

Lower densities had higher cumulative fruit yields tree^{-1} (Table 4) but cumulative fruit yield ha^{-1} was higher at the higher densities. The relation between density and cumulative oil yield followed the same

Table 3. Regression analysis of the production response to density for the 3rd, 5th, 6th and 7th year from planting. Parameters of intercept and density (trees ha^{-1}) are indicated, as well as coefficient of determination. For all traits and years the model was highly significant ($P < 0.001$)

Traits	Year	Intercept	Density	R^2
Fruit yield (kg tree^{-1})	3rd	8.56	–0.0015	0.37
	5th	10.48	–0.0019	0.48
	6th	9.32	–0.0021	0.41
	7th	8.17	–0.0016	0.53
	Accumulated	36.54	–0.0072	0.56
Fruit yield (kg ha^{-1})	3rd	3,281	3.71	0.57
	5th	4,231	4.36	0.67
	6th	4,461	2.72	0.43
	7th	3,435	3.03	0.72
	Accumulated	15,410	13.84	0.72
Oil yield (kg ha^{-1})	3rd	668.3	0.49	0.47
	5th	992.0	0.68	0.57
	6th	937.7	0.59	0.41
	7th	745.5	0.72	0.69
	Accumulated	3,343.5	2.50	0.69

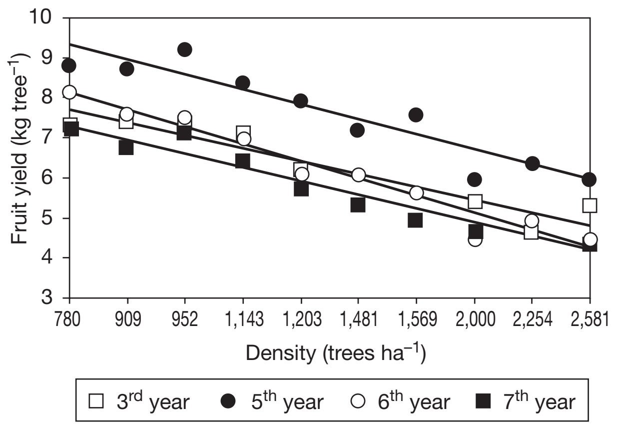

Figure 1. Time trend of olive production tree^{-1} in response to tree density in the 3rd, 5th, 6th and 7th year after planting (regression lines are indicated).

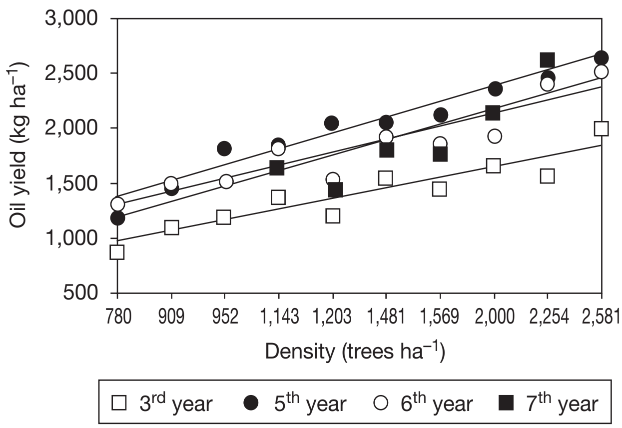

Figure 3. Time trend of oil production ha^{-1} in response to tree density in the 3rd, 5th, 6th and 7th year after planting (regression lines are indicated).

trend as fruit yield, i.e. there was more oil ha^{-1} at higher densities.

Discussion

This paper reports the initial results of the first olive density trial in a hedgerow orchard. During the seven first years after planting, it seems that there was no strong effect of competition among trees in the higher density treatments so their lower yield tree^{-1} was compensated for the higher number of trees ha^{-1}. A significant linear increase in yield with increased density was maintained for seven years after initial planting.

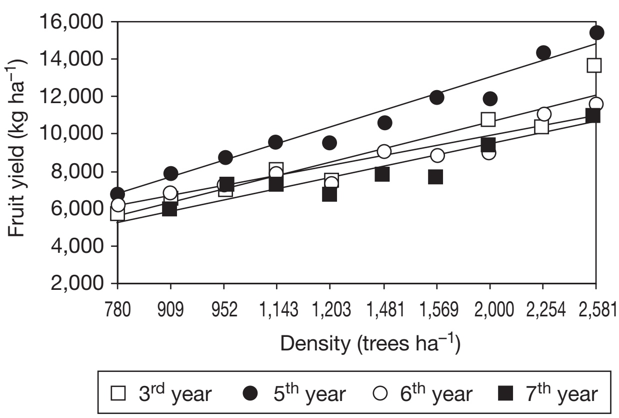

Figure 2. Time trend of olive production ha^{-1} in response to tree density in the 3rd, 5th, 6th and 7th year after planting (regression lines are indicated).

Similar yield:density correlations have been obtained for nine years in apple (Hampson *et al.,* 2004). In other medium- and long-term spacing trials in both apple and peach, high density treatments were also the most productive (Westwood *et al.,* 1976; Marini and Sowers, 2000). The absence of a significant difference in fruit characteristics among densities was similar to results on apple fruit characters density trials (Widmer and Krebs, 2001).

The accumulated yield of 51 Mg ha^{-1} of olives, at the highest density, was higher than the approximately 36 Mg ha^{-1} of olives, for the same period and cultivar, grown at similar spacing in Catalonia (Tous *et al.,* 2007). This may reflect more favourable growing conditions for olives in Andalusia, especially given that yield would have been higher still if the data for the 4th year after planting was included. In other olive spacing trials, at lower densities, there was an increase in yield with density in the first 9-10 yr after planting (Pastor and Humanes, 1990; Tous *et al.,* 2005).

In summary, seven years after planting, the expected stronger competition and mutual shading at higher densities had not negatively influenced olive production and oil content. It is, however, essential to verify if, in coming years, it is possible to control tree vigour, especially in high density treatments, to avoid problems produced by shading and such diseases as *Spilocea olegina* and *Verticillium dahliae*. An important question is what density is required to combine a high early yield with stability to maximize yield in the long term (15-20 yr in hedgerow orchards). The present data give an idea of the minimum number of plants ha^{-1}, and therefore the minimum investment for maximum

Table 4. Response of four years of accumulated yield (3[rd], 5[th], 6[th] and 7[th] years) to tree density (data from 4[th] year after planting not included)

Density (trees ha^{-1})	Fruit yield (kg tree^{-1})	Fuit yield (kg ha^{-1})	Oil yield (kg ha^{-1})
780	31.5	24,573	4,705
909	30.5	27,723	5,521
952	31.3	29,816	6,083
1,143	28.9	33,067	6,687
1,203	25.9	31,219	6,244
1,481	24.7	36,654	7,345
1,569	23.7	37,281	7,218
2,000	20.5	41,161	8,099
2,254	20.7	46,767	9,074
2,581	20.1	51,888	9,732

production in this new type of olive orchard. Future work will require further testing in blocks which are large enough to include the competitive relationships between trees in a commercial planting.

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